Shen Kua | Encyclopedia.com

Complete Dictionary of Scientific Biography COPYRIGHT 2008 Charles Scribner's Sons
115-146 minutes

(*b*. 1031, registered at Ch'ien-t'ang[2] [now Hangchow, Chekiang province], China; *d*. Ching-k'ou, Jun prefecture[3] [now Chinkiang, Kiangsu province], China, 1095)

Polymathy, astronomy.

Shen was the son of Shen Chou[4] (*ca*. 978–1052) and his wife, whose maiden name was Hsu.[5] Shen Chou came of a gentry family with neither large landholdings nor an unbroken tradition of civil service. He spent his life in minor provincial posts, with several years in the capital judiciary. Shen Kua apparently received his early education from his mother. A native of Soochow (the region of which was known for its flourishing manufactures, commerce, and agriculture), she was forty-four or forty-five years old when he was born. Shen's background made possible his entry into the imperial bureaucracy, the only, conventional road to advancement for educated people of his time. Unlike colleagues who came from the ancient great clans, he could count on few advantages save those earned by his striving and the full use of his intellectual talents. Shortly after he was assigned to the court, he became a confidant of the emperor and played a brilliant part in resolving the crises of the time. But within slightly over a decade his career in the capital was ended by impeachment. After a provincial appointment and five years of meritorious military accomplishment, he was doubly disgraced and politically burned out. The extremes of Shen's career and the shaping of his experience and achievement in science and technology become comprehensible only if the pivotal circumstances of his time are first considered.

Historical Background. Shen's time was in many senses the climax of a major transition in the chinese polity, society, and economy.

Three centuries earlier the center of gravity in all these respects still lay in the north, the old center of civilization of the Han people. Wealth and power rested in the hands of the old aristocratic landowning families. Governmental institutions incorporated the tension between their private interests and the inevitable desire of their foremost peer, the emperor, to concentrate authority. The civil service examination system was beginning to give the central government a means to shape a uniform education for its future officials; but since birth or local recommendation determined who was tested, the mass of commoners remained un-involved. The social ideals prevalent among the elite were static; the ideal past was cited to discourage innovation; and the moral example of those who ruled, rather than responsive institutions or prescriptive law, was held to be the key to the healthy state. The classicist's paradigm of a two class society—self-sufficient agriculturalists ruled and civilized by humane generalists, with land as the only true wealth—did not encourage commerce, industry, or the exploitation of natural resources. The wants of the great families, whose civil servant members were becoming city dwellers by the middle of the eighth century, nonetheless gave momentum to all of these activities; but the majority of the population still took no part in the rudimentary money economy.

The T'ang order began a long, slow collapse about 750, until in the first half of the tenth century the empire of "All Under Heaven" was reduced to a succession of ephemeral and competing kingdoms. When the universal state was reconstructed in the Northern Sung (960–1126). its foundations were in many important respects different from those of the early T'ang. A new dynasty was not only, as classical monarchic theory had it, a fresh dispensation of the cosmos; it was also the occasion for institutionalizing a new distribution of power in society. The cumulative result of changes in taxation had been to make the old families accountable for their estates as they had not been earlier, and to encourage smaller landholdings–and, thus, a wider diffusion of wealth.

The center of vitality had moved southeast to the lower Yangtze valley, which had long before emerged as the major rice-yielding region. By this time its fertility, combined with its relative freedom from restrictive social arrangement, had bred a new subculture that was more productive in industry than elsewhere and hospitable to the growth of commerce and stable markets, the beginnings of a uniform money economy, and the great broadening of education that printing had just made possible. The cew southern elite was, on the whole, small gentry, and lacked the military traditions of the ancient northern clans and of power holders in the period of disunion. Their families were often too involved in trade for them to despise it. Although conservative, as all Chinese elites have been, they were prepared to think of change as a useful tool. The novelties of attitude and value were often slighter or subtler than such a brief account can convey, but within the established limits of Chinese social ideals their considerable.

In Shen Kua's time the old families still provided many of the very highest officials and thus wielded great influence, positive or obstructive, in discussion about the future of China. But they had become merely influential members of a new political constellation that brought a variety of convictions and interests to that brought a variety of convictions and interests to that perennial debate. An especially obvious new element was that many southern small gentry families like Shen's established traditions of civil service, either as a main means of support or to protect and further their other concerns. Once a family's social standing was achieved. one or more members could enter the bureaucracy freely because of experience as subordinates in local administration or because they were amply prepared by education for the examinations. Their sons could enter still more freely because special access to both direct appointment and examination was provided to offspring of officials.

Not sharing the old vision of a virtue-dominated social order fixed by precedent, men of the new elite were willing to sponsor institutional renovation in order to cope directly with contemporary problems. Dependent on their own talents and often needing their salaries, they were dedicated to building a rational, systematic, and in most respects more centrally oriented administration. They were willing to make law an instrument of policy, and insisted that local officials be rated not only on the moral example they set but also quantitatively–on how effectively they made land arable and collected taxes. In the name of efficiency they devoted themselves to removing customary curbs on imperial authority and (with only partial success in the Sung) to dismantling the structures of privilege that underlay regional autonomy. Only later would it become clear that they were completing the metamorphosis of the emperor from paramount aristocrat to autocrat. At the same time they were successfully demanding more policy-making authority as the emperor's surrogates, although at the cost to themselves of greater conformity than officials of the old type had willingly accepted.

This irreversible transition did not lead to a modern state, but only to a new and ultimately stagnant pattern. The most accelerated phase of a change was the activity of what is called the New policies[6] group (actually a shifting coalition) between 1069 and 1085. Its leader, Wang An-shih[7] (1021–1086), was brought to the capital in 1068 by the young emperor Shen-tsung, who had just taken the throne. Within two years Wang had become first privy councillor. He resigned for nine months in 1074, when pressure from his antagonists persuade the emperor to be less permissive, and returned permanently to private life in 1076. The New policies continued to be applied and extended. but with less and less attention to their founding principles. until Shen-tsung's death in 1085. Under the regency of the empress dowager, enemies of the reform attempted for eight years to extirpate Wang's influence and take revenge upon his adherents. When Emperor Che-tsung came of age in 1093, the New policies were revived, but were so bent toward selfish ends and administered so disastrously that the word "reform" is hardly applicable.

Wang An-shih's opponents were many: the old aristocrats, career bureaucrats of the sort who would oppose any change as disruptive, officials whose individual or group interests ran in other directions-and men of group interests ran in other directions-and men of high ideals who found his proposals ill-advised and his personal style too intolerant.[*]

No institution had evolved through Chinese history to work out and resolve conflicts of political viewpoint. This lack was filled by cliques, intrigues, and appeals to imperial intervention. Division and corruption among active supporters of the New Policies also had been a problem from the start. The scope of Wang's program was so large that he had to take competent support where he found it. The new access to power that he offered attracted ambitious men, many of whom had little real sympathy for his convictions and dedicated themselves primarily to manipulation and graft. Once Wang was gone, the leadership of his group tended to become a battleground for aspirations of this kind. The internal and external enemies of the New Policies left the program a shambles by the time the Chin Tartars drove the Sung south in 1127.

A primary aim of the reforms was financial security of the state, which prompted initiatives in water control and land reclamation, encouragement of extractive industries and agriculture, intervention in commerce, and rationalization of taxes. Another goal, particularly at the emperor's insistence, was military strength. There had been a long confrontation between the Chinese and the powerful Khitan empire, pastoral masters of mounted combat to the north (renamed Liao in 1066). Seventy years of fitful peace were punctuated by humiliating Chinese failures to recapture territory south of the Great Wall and maintained by large annual bribes. For three decades the Tangut people of the north-west had posed an almost equally unpalatable demand for appeasement. Victory or détenet through strength, the emperor hoped, could be bought on both fronts with the wealth that the New Policies generated from man's exploitation of nature. Here too expertise was needed in cartography, strategic theory and tactical doctrine (both of which contained cosmological elements), design and manufacture of war matériel, fortification, troop organization and training, and development of a stable economy in border regions.

[*] In the successive reform movements of the Northern Sung there were considerable differences in the alignment of men with different beliefs and backgrounds. See the discussion in James T. C. Liu, "An Early Sung Reformer: Fan Chung-yen." in John K. Fairbank, ed., *chinese Thought and institutions* (Chicago, 1957), 105–131. esp. 107–109. The generalizations of the present article and of current scholarship as a whole are crude and tentative, pending the "comparative analysis of the inter-relationships between ideology and family, class, status-group, and regional interests" that Robert M. Hartwell has called for in "Historical Analogism, Public Policy, and Social Science in Eleventh-and Twelfth-century China," in *American Historical Review*, **76** (1971), 690–727.

Shen Kua contributed to nearly every field of New Policies activity, both civil and military. His social background and political commitments cannot be considered responsible for his scientific talent or curiosity; the antecedents and loyalties of other major contemporary scientific figures were very different from his. But a review of his career and of his work will show how regularly his involvement with particular technical themes and problems grew out of his activities in government.

Life . From about 1040 Shen traveled with his father to successive official posts from Szechwan in the west to the international port of Amoy. He was exposed not only to the geographical diversity of China but also to the broad range of technical and managerial problems—public works, finance, improvement of agriculture, maintenance of water-ways—that were among the universal responsibilities of local administrators. Because his physical constitution was weak, he became interested in medicine at an early age.

Late in 1051, when Shen was twenty, his father died. As soon as the customary inactivity of the mourning period ended in 1054, Shen received the first of a series of minor local posts; his father's service exempted him from the prefectural examination. His planning ability became almost immediately apparent when he designed and superintended a drainage and embankment system that reclaimed some hundred thousand acres of swampland for agriculture. This was the first of a seried of projects that established his reputation for skill in water control. In 1061, as a subprefect in Ning-kuo [8] (now Fu-hu, [9] Anhwei province), after a cartographic survey and a historical study of previous earthworks in the region, he applied the labor of fourteen thousand people to another massive land reclamation scheme that won the recognition of the emperor. In a series of floods four years later, Shen noted, it was the only such project not over- whelmed. He wrote characteristically that in the first year it returned the cost of the grain used, and that there was more than a tenfold profit on cash expended. In 1063 he passed the national examinations. Posted to Younchow, he impressed the fiscal intendant (a post then equivalent to governor), Chang Ch'u[10] (1015–1080), who recommended him for a court appointment leading to a career in the professional financial administration.[*]

[*] The succession of fiscal posts that often led to a seat on the Council of State in the eleventh century has been documented by Robert M. Hartwell in "Financial Expertise, Examinations, and the Formulation of Economic Policy in Northern Sung China," in *Journal of Asian Studies*, **30** , 281–314.

Shen apparently used the time not occupied by his early metropolitan appointments, which were conventional and undemanding, to study astronomy. In reply to the informal questions of a superior he set down clear explanations, still extant, of the sphericity of the sun and moon as proved by lunar phases, of eclipse limits, and of the retrogradation of the lunar nodes. They demonstrate an exceptional ability to visualize motions in space, which were at best implicit in the numerical procedures of traditional astronomy and seldom were discussed in technical writing. In 1072 Shen was given an additional appointment as director of the Astronomical Bureau. With the collaboration of his remarkable commoner protégé Wei P'u[11] and the aid of other scholarly amateurs, using books gathered from all over the country, he undertook a major calendar reform. He planned an ambitious series of daily observations to extend over five years, using renovated and redesigned instruments. When he took office, the bureau was staffed with incompetents. He forced the dismissal of six whom he caught falsifying records of phenomena, but the obstruction of those who remained doomed his program of observations and kept his new system of ephemerides computation from being among the two or three most securely founded before modern times. Shen's personal involvement in later stages of the reform undoubtedly was limited by his gradual movement into the vortex of factional politics.

Shen was early known to Wang An-shih, who composed his father's epitaph while a young provincial official; Shen eventually came to be publicly identified by enemies of the New Policies as among the eighteen members of Wang's intimate clique. In late 1072, in support of Wang's program, Shen surveyed the silting of the Pien Canal near the capital by an original technique, dredged it, and demonstrated the value of the silt as fertilizer. Until mid–1075 he spent much time traveling as a troubleshooter of sorts, inspecting and reporting on water control projects, military preparations, and local administrations—and, it has been conjectured, providing encouragement to Wang's provincial supporters. Shen was put in charge of arsenal activities and, in 1075, was sponsored by Wang (then head of government) to revise defensive military tactics, a task the throne had proposed for Wang himself.

In 1074 the Khitan were pressing negotiations to move their borders further south. Incompetent and timorous Chinese negotiators were conceding unfounded Liao assertions about the language and substance of previous agreements. Shen built a solid Chinese case by going to the archives, as no one had bothered to do before. His embassy in mid-1075 to the camp of the Khitan monarch on Mt. Yung-an[12] (near modern P'ing-ch'üan.[13] Hopei) was triumphant. He described himself surrounded by a thousand hostile onlookers, calling on his staff, who had memorized the old documents of the Khitan themselves, to cite without pause or flurry the exact reference to refute one historical claim after another.

Shen returned to China—with biological specimens and maps of the territories he had passed through—to become a Han-lin academician, to be given charge of a large-scale water control survey in the Yangtze region, and then to become head of the Finance Commission. While in this very powerful position he untangled a variety of contra dictory policies, producing in the process some of the most penetrating writings before modern times on the operation and regulation of supply and demand, on methods of forecasting prices in order to intervene effectively in the market, and on factors that affect the supply of currency (varying through hoarding, counterfeiting, and melting) as the value of the metal in it fluctuates about its controlled monetary value. In the autumn of 1077, just as his revision of critical fiscal measures was well launched, he was impeached by the corrupt and vindictive censor Ts'ai Ch'ueh[14] (1036–1093). The charge was that Shen had opposed a New Policies taxation measure in an underhanded, inconsistent, and improper way. It was credited by historians for centuries, but its truth has been refuted in every detail by recent Chinese research. His protector Wang An-shih had just left government; it is believed, given the mood of the time, that by threatening an established budget item in order to ease the burdens of the poor, Shen became an easy victim of factional maneuvering.

The emperor was not only the ritual synapse between the political and natural orders; he was a human being whose likes and dislikes were indulged within broad limits that could be further widened by force of his personal charisma and will. The closer to him an official penetrated, the more achievement and even survival became subject to imperial whim and the intrigue of colleagues. Although the record is fragmentary, it gives the impression that Shen Kua was maneuvered by Wang An-shih into the proximity of the throne because of his brilliance, judgment, and effectiveness at complicated tasks. Nothing indicates that he was adept at protecting himself. He attracted the most damaging animosity not from opponents of the New Policies but from designing members of his coalition. Once the emperor qualified his support of the New Policies in 1074, the risk of debacle remained great and imminent. Many officials who had risen with Wang fought furiously for the power that would keep them afloat even though the program sank. They did not wish to be deterred by a colleague who judged issues on their own merits. They probably also felt, as others did, that a man of Shen's age and rank did not deserve the emperor's confidence.

Ts'ai Ch'ueh was rising into the vacuum that Wang's retirement had left. The emperor depended increasingly on Ts'ai's monetary counsel and could not easily dusregard what he insisted ypon. For three years it was impossible to overcome his objections and those of another censor, and to rehabilitate Shen. Finally Shen was sent to Yenchou[15] (now Yenan, Shensi province), on the necessary route for military operations by or against the Tanguts, as commissioner for prefectural civil and military affairs.[16] The Tanguts were then divided and weakened, minor Chinese conquests around 1070 had set the stage fro a war, and the treasury had ample funds. Shen plauyed an important part in organizing and firtifying for the victorious offensive of the autumn of 1081. In extending Sung control he showed a practical as well as a theoretical mastery of the art of warfare. He was cited for merit and given servelal honorary appointments. It was probably at the same time that he was ennobled as state foundation viscount.[17] In his sixteen months at Yen-chou, Shen received 273 personal letters from the emperor. His standing at the court was in principle reestablished. Whether he had become shrewd enough to survive there was never tested.

Shen and a colleague followed up the victory by proposing fortifications to close another important region to the Tanguts. The emperor referred the matter to an ambitious and arrogant official who, ignoring the proposal, changed the plan to provide defenses for what Shen argued was an indefensible and strategically useless location. Shen was commanded to leave the vicinity of the new citadel so as not share in the credit for the anticipated victory. When the Tangut attack came, the emissary's force was decimated while Shen, with imperial permission, was successfully defending a key town on the enemy invasion route to Yen-chou. The campaign thus provided the Tangut with no opening for advance—but Ts'ai Ch'ueh was now a privy councillor. As titular military commander Shen was held respossible for the defeat and considerable loss of life. At the age of fifty-one his career was over. The towns he saved were later abandoned by the anti—New Policies regime to no advantage, just as the lands he had saved from the Khitan through diplomacy had since been lost by another negotiator.

Shen spent six years in fixed probationary residence, forbidden to engage in official matters. He used at least two of these years to complete a great imperially commissioned atlas of all territory then under Chinese control. He had been working on this atlas intermittently earlier, he had had access to court documents. His reward included the privilege of living where he chose.

Ten years earlier Shen had bought, sight unseen, a garden estate on the outskirts of Ching-k'ou In 1086, visiting it for first timed, he recognized it as a landscape of poignant beauty that he had seen repeatedly in dreams, and named it Dream Brook (*Meng ch'i*, [18] alternately read *Meng hsi*). He moved there in 1088. Despite a pardon and the award of sinecures to support him in his old age, he spent seven years of leisure, isolation, and illness until his death there.[*]

Shen's writings, of which only a few are extent even in part, include commentaries on Cofunction missions, a collection of literary works. and monographs on rituals, music, mathematical harmonics, administration, mathematical astronomy, astronomical instruments, defensive tactics and fortification, painting, tea, medicine, and poetry. Of three books complied during his last years at Dream Brook, one, "Good Prescription" (*Liang fang*[19]), was devoted to medical therapy. theory, and philology; the other belong to particularly Chinese gerneres, "Record of Longings Forgotten" (*Wang Huai lu*[20]), a collection of notes on the life of the gentleman farmer in the mountains, contains useful information on implements and agricultural technique and. unlike more conventional agricultural treatises up to that time, on the culture of medicinal plants.

"Brush Talks From Dream Brook" (*Meng ch'i pi t' an*[21]) and its sequels and well-edited in modern times, is by any reckoning one of the most remarkable documents of early science and technology. It is a collection of about six hundred recollections and observations, ranging from one or two sentence to about a page of modern print—"because I had only my writing brush and ink slab

[*]*For a translation that conveys the flavor of Shen's autobiography, see Donald Holzman, "Shen Kua," 275–276.*

to converse with, I call it Brush Talks." They are loosely grouped under topics (seventeen in all current versions), of which seven contain considerable matter of interest in the study of nature and man's use of it: "Regularities Underlying the Phenomena"[22] (mostly astronomy, astrology, cosmology, divination), "Technical Skills"[23] (mathematics and its applications, technology, medicine), "Philology[24] (including etymology and meanings of technical terms). "Strange Occurrences"[25] (incorporating various natural observations), "Artifacts and Implements"[26] (techniques reflected in ancient objects), "Miscellaneous Notes"[27] (greatly overlapping other sections), and "Deliberations on Material Medica"[28] (most of it on untangling historic and regional confusions in identities of medical substances).

Notices of the highest originality stand cheek by jowl with trivial didacticisms, court anecdotes, and ephemeral curiosities under all these rubrics; other sections were given to topics conventional in collections of jottings—memorable people, wisdom in emergencies, and so on. Shen's theoretical discussions of scientific topics employed the abstract concepts of his time—yin-yang, the Five Phases (*wu-hsing*[29]), *ch'i*[30] and so on. A large fraction of the book's contents is devoted to fate, divination, and portents, his belief in which has been ignored by historians seeking to identify in him the prototype of the modern scientist. The author of "Brush Talks" has been compared with Leibniz: and in an era of happier relations with the Soviet Union, Hu Tao-ching, the foremost authority on Shen, referred to him as the Lomonosov of his day. But Shen was writing for gentlemen of universal curiosity and humanistic temperament; custom, wisdom, language, and oddity were as important themes as nature and artifice.

Because Shen's interests were multifarious, the record unsystematic, and its form too confining for anything but fragmentary insight, only accumulation can provide a fair impression of what constitutes his importance. What follows is the mere sample that space allows of his attempts to deepen the contemporary understanding of nature, his observations that directed the attention of his educated contemporaries to important phenomena or processes, and his own technical accomplishments. They are grouped to bring out contiguity of subject matter without interposing the radically different disciplinary divisions of modern science. These sample will become the basis of discussion—which, given the state of research, must be highly tentative—of the epistemological underpinnings of Shen's work, and of the unity of his scientific thought with elements that today would be considered unscientific, primitive, or superstitious. Finally, it will be possible to evaluate Shen's life as a case study in the reconcilability of Confucianism and science, which the conventional wisdom among sinologists for over a generation has tended to place in opposition.

Quantity and Measure . Mathematics was not the queen of sciences in traditional China. It did not exist except as embodied in specific problems about the physical world. Abstract thought about numbers was always concerned with their qualities rather than their properties, and thus remained numerology. This art, although it blended into arithmetic, was only partly distinct from other symbolic means (in the anthropologist's sense: magical, ritual, religious, divinatory) for exploring the inherent patterns of nature and man's relation to it. Computation, on the other hand, was applied to a great variety of mensurational, accounting, and other everyday tasks of the administrator in a coherent tradition of textbooks. Occasionally curiosity and skill pushed beyond these pragmatic limits, but never very far. Some of the problems that Shen presented in "Brush Talks" had no application, but his enthusiasm for them was in no way qualified.

In addition to this accumulation of individual problems there were two exact sciences, in which mathematics served theory to advance knowledge of the patterns underlying the phenomena. One was mathematical harmonics (lü lü[31]), which explored the relations between musical intervals and the dimensions of instruments that produced them, in ways analogous to the Pythagorean art. Its appeal was much the same in both China and Greece: it demonstrated how deeply the power of number was grounded in nature. For this reason in China mathematical harmonics was often put into the same category as mathematical astronomy, which also had foundations in metaphysics. Astronomy, by far the more technically sophisticated of the two exact sciences, was normally employed on behalf of the monarch. Unpredictable phenomena and failures of prediction were either good or bad omens. Bad omens were interpreted as warnings that the emperor's mediating virtue, which maintained concord between the cosmic and political orders, was deficient. Successful prediction of celestial events was symbolic preservation or enhancement of the charisma of the ruling dynasty.

The annual calendar (or almanac) issued by authority of the throne was thus of great ceremonial importance. It encompassed all predictable phenomena, including planetary phenomena and eclipses. The utilitarian planetary phenomena and eclipses. The utilitarian calendrical aspects—lunar months and solar years—had long since been refined past any practical demand for accuracy, but astronomical reinforcement of the Mandate of Heaven called forth endless attempts at greater precision of constants. As it became conventional to institute a complete new system for computing these ephemeredes when a new emperor was enthroned, technical novelty was at a premium. When new ides were unavailable, trivial recasting of old techniques was usually substituted. Repeated failures of prediction were another motive for reform of the astronomical system. In such cases too the system was in principle replaced as a unit rather than repaired. most systems survived or feel on their ability to predict eclipses, particularly solar eclipses. These were the least amenable of all celestial phenomena to the algebraic, non-geometric style of mathematics. Prior to Shen's time little effort had gone into predicting the apparent motions of the planets, which lacked the immediacy of solar and lunar phenomena. This was, in fact, an omission that Shen seems to have been the first to confront.

General Mathematics. As wood-block printing became widespread, the government used it to propagate carefully edited collections of important ancient textbooks for use in education. This was being done in medicine at the time Shen entered the capital bureaucracy. In 1084 a collection of ten mathematical manuals, made four centuries earlier and reconstituted as well as extant texts allowed, was printed. The authority of these projects served both to fix textual traditions, preserving selected treatises from further attrition, and passively to encourage the fading into oblivion of books left out. Shen thus lived at a pivotal period in the development of mathematics, and his judgments on lost techniques and disused technical terms (such as 300, 306) have played an important part in later attempts to interpret them.[*]

[*] Numbers in parentheses are item numbers in the Hu Taoching edition of *Meng ch'i pi t' an* (the latter is referred to hereafter as "Brush Talks"). Roman volume numbers followed by page numbers refer to translations in Joseph Needham *et al., Science and Civilisation in China*. Where my own understanding differs considerably from Needham's, an asterisk follows the page reference. All quotations below are from Shen, and all translations are my own. Full bibliographical data are given in the notes only for sources of too limited pertinence to be included in the bibliography. Chinese and Japanese family names precede personal names throughout this article.

"Brush Talks" is also an essential source for the study of pre-Sung metrology, currency, and other subjects related to computation.

Shen used mathematics in the formulation of policy arguments more consistently than most of his colleagues; examples are his critique of military tactics in terms of space required for formations (579) and his computation that a campaign of thirty-one days is the longest that can feasibly be provisioned by human carriers (205). But of the computational methods discussed in his "Technical Skills" chapter, those not related to astronomy are almost all abstractly oriented.

This original bent emerges most clearly in two problems. One departs from earlier formulas for computing the frustum of a solid rectangular pyramid. Shen worked out the volume of the same figure if composed of stacked articles (he mentioned *go* pieces, bricks, wine vats) that leave interstices (301). Since Shen intended this "Volume with interestices" (*ch'i chi*[32]) method to be applicable regardless of the shape of the objects stacked, what he gave is a correct formula for the number of objects, which are thus to be considered of unit volume. His presentation has several interesting features. Needham has suggested that the concern with interestices (and, one would add, unit volumes) may have been a step in the direction of geometric exhaustion methods (III, 142–143)—although it was tentative and bore fruit only in seventeenth-century Japan. Second, instead of the worked-out problem with actual dimensions that is conventional in early textbooks, Shen simply gave a generalized formula; "double the lower length, add to the upper length, multiply by the lower length, add to the upper length, multiply by the lower width," and so on. Third, this was the earliest known case in China of a problem involving higher series. Built on earlier numerical approaches to arithmetical progressions, it provided a basis for more elaborate treatment by Yang Hui[33] (1261) and Chu Shihchieh[34] (1303).

The second problem of interest was said "in a story" to have been solved by one of China's greatest astronomers, the Tantric Buddhist patriarch I-hsing[35] (682–727): the number of possible situations on a *go* board, with nineteen by nineteen intersections on which any number of black or white pieces may be placed. Whether I-hsing actually solved this problem we do not know; Shen's single paragraph was the first and last known discussion of permutations in traditional mathematics. It stated the order of magnitude of the answer—"approximately speaking one must write the character wan[36] (10,000) fifty-two times in succession"—adding exact answers for smaller arrays, three methods of solution, and a note on the limited traditional notation for very large numbers (304)[*].

Mathematical Harmonics. The Pythagoreans were fascinated by the relations of concordant intervals to the plucked strings that produced them, since the lengths between stops were proportionate to simple ratios of integers. The Chinese built up a similar science on a gamut of standard pipes. Beginning with a pipe eight inches long and 0.9 inch in diameter, they generated the lengths of subsequent pipes by multiplying the previous length alternately by 2/3 and 4/3, making twelve pipes within an approximate octave. The dozen were then related to such categories as the twelve divisions of the tropical year, in order to provide a cosmic basis for the system of modes that the pipes determined. A pentatonic scale, which could be used in any of the twelve modes, provided similar associations with the Five Phases. This basis was extended to metrology by defining the lengths and capacities of the pipes in terms of millet grains of standard dimensions. Shen provided a lucid and concise explanation of these fundamentals of mathematical harmonics, and corrected grotesque complications that had crept into a canonic source through miscopying of numbers (143, 549). He also experimentally studied stringed instruments. By straddling strings with paper figures, he showed that strings tuned to the same notes on different instruments resonate, as do those tuned an octave apart on the same instrument (537; cf. IV.1, 130). His two chapters on music and harmonics[37] are also a trove of information on composition and performance.

Astronomy. Shen's major contributions in astronomy were his attempts to visualize celestial motions spatially, his are-sagitta methods that for the first time moved algebraic techniques toward trigonometry, and his insistence on daily observational records as a basis for his calendar reform. The first had no direct application in computation of the ephemerides, although it may well have inspired (and at the same time have been inspired by) the second, which grew out of traditional mensurational arithmetic. It has been suggested that the clarity of Shen's cosmological explanations led to his appointment to the Astronomical Bureau.

[*] This was translated in part by Needham (III.139). The extant text, even in Hu's edition, is very corrupt. It has been edited and considerably emended by ch'ien Pao-tsung in *Sung Yuan shuhsueh-shih lun-wen-chi*. 266–269.

which provided opportunity for his contributions in the second and third areas. But circumstances that arose from the bureaucratic character of mathematical astronomy made these contributions futile in his lifetime.

Shen's discussions of solar, lunar, and eclipse phenomena (130–131; excerpts, III, 415—416) have been mentioned. By far the most remarkable of his cosmological hypotheses attempted to account for variations in the apparent planetary motions, including retrogradation. This concern is not to be taken for granted, since traditional astronomers preferred purely numerical approaches to prediction, unlike the spatial geometric models of Greek antiquity, and showed little interest in planetary problem. Noting that the greatest planetary anomaly occurred near the stationary points, Shen proposed a model in which the planet traced out a figure like a willow leaf attached at one side to the periphery of a circle (see Figure 1). The change in direction of the planet's motion with respect to the stars was explained by its travel along the pointed ends of the leaf (148).[*] The willow leaf, in other words, served one of the same functions that the epicycle served in Europe. It is characteristic that, having taken a tack that in the West was prompted entirely by geometric reasoning, Shen's first resort should have been a familiar physical object. Use of a pointed figure doubtless would not have survived a mathematical analysis of observational data, but this remained an offhand suggestion.

Another early outcome of Shen's service at the court was a series of proposals for the redesign of major astronomical instruments: the gnomon, which was still employed to measure the noon shadow and fix the solstices; the armillary sphere, with which angular measurements were made; and the clepsydra, used to determine the time of observations (and to regulate court activities). Shen's improved versions of the latter two apparently were not built until late 1073, after he had taken charge of the Astronomical Bureau. The armillary at least was discarded for a new one in 1082, a casualty of his personal disgrace.

Shen's clepsydra proposals represent a new design of the overflow-tank type (Needham's Type B; III, 315–319, 325), but the most significant outcome of his work on this instrument was a jotting on problems of calibration. Day and night were by custom separately divided into hours, the

* Translated by N. Sivin. *Cosmos and Computation in Early Chinese Mathematical Astronomy* (Leiden, 1969), also published in *Toung Pao*. **55** (1969), 1–73 (see 71–73), from which the figure is reproduced with permission of E. J. Brill.

length of which varied with the season. The time was read off graduated float rods, day and night sets of which were changed twenty-four times a year. Shen pointed out that this crude and inadequate scheme amounted to linear interpolation, "treating the ecliptic as a polygon rather than a circle," and argued for the use of higher-order interpolation (128).

The best armillary sphere available in the central administration when Shen first worked there was based on a three-hundred-year-old design "and lacked ease of operation" (150). The most interesting of Shen's improvements was in the diameter of the naked-eye sighting tube. At least from the first millennium b.c. a succession of stars had been taken up and abandoned as the pole star. In the late fifth century of the current era Tsu Keng[38] discovered that the current polestar, 4339 Camelopardi, rotated about a point slightly more than a degree away. This determination of the true pole was incorporated in subsequent instruments by making the radius of their sighting tubes 1.5 Chinese degrees (each 360/365.25°). The excursion of the pole star just inside the field of view thus provided a nightly check on orientation. Six hundred years later Shen found that the polestar could no longer be kept in view throughout the night. He gradually widened the tube, using plots of the polestar's position made three times each night for three months to adjust aim, until his new calibration revealed that the distance of the star from "the unmoving place at the celestial pole" was now slightly over three degrees (127; **III** , 262). Shen's successors followed him in treating the distance as variable, although the relation of this secular change to the equinoctial precession was not explored. Aware of the periodic retrogradation of the lunar nodes, Shen also discarded the armillary ring representing the moon's path, which could not reflect this motion; it was never used again.

Calendar Reform. On the accession of Shentsung in 1068, a new computational system was expected. The inability of the incumbent specialists to produce one left Shen with a clear mandate when he took over the Astronomical Bureau in 1072. The situation became even more awkward when he was forced to bring in Wei P'u and others from outside the civil service, although few of the incompetents already in the bureau could be dislodged, in order to begin work on the calendar reform. It is not yet possible to tell what part of the work was done by Shen and what part by his assistants, although it is clear that Wei took responsibility for compiling the system as Shen became increasingly occupied elsewhere in government. Wei, a commoner whose connection with Shen was first reported in 1068, bore the brunt of fervent opposition within the bureau. He was even formally accused of malfeasance.

Shen knew that previous Sung astronomical systems had suffered greatly from reliance on old observations, and had a clear conception of what new data were needed for the first major advance in centuries. Unabating opposition within the bureau and his own demanding involvements outside it limited the number of innovations of lasting importance in his Oblatory Epoch (*Feng-yuan*[39]) system. It was the official basis of calender computation from 1075, the year of its completion, to 1094, a period very close to the average for systems of the Northern Sung. That the system was not used longer has little to do with its merits, since except in cases of spectacular failure, Sung astronomical systems changed as rulers changed. Shen's was replaced when a new era was marked by the coming of age of Che-tsung. The immediate vicissitudes and long-term influence of three special features will give a general idea of the limits that historical actuality set upon Shen's astronomical ambitions.

The boldest aspect of Shen's program was the attempt to master the apparent motions of the planets–not merely their mean speeds and prominent pheomena–for the first time. This could not be done with a few observations of stationary points. occultations, and maximum elongations. Shen and Wei therefore planned a series of observations of a kind not proposed in Europe until the time of Tycho Brahe, five centuries later; exact coordinates read three times a night for five years. Similar records were to be kept for the moon's positions, since previous Sung systems had still used the lunar theory of I-hsing, which after 350 years had accumulated considerable error. These records were the most unfortunate casualty of the antagonism within the Bureau. Shen and Wei had no recourse but to produce a conventional planetary theory based mainly on old observations. They were able to correct the lunar error, but even this proposal provoked such an outcry that it could be vindicated only by a public demonstration using a gnomon (116).

A second issue was the central one of eclipse prediction. Previous attempts to add or subtract correction factors showed the futility of this approach. It was Wei P'u who "realized that, because the old eclipse technique used the mean sun, [the apparent sun] was ahead of it in the accelerated phase." He therefore incorporated apparent solar motion into the eclipse theory (139). This had been done centuries earlier but abandoned.

A major obstacle in eclipse prediction, as well as in such workaday problems as the projection of observations in equatorial coordinates onto the ecliptic, was the absence of spherical geometry. Shen's evolution of arc-chord-sagitta relations out of some inferior approximations for segment areas given in the arithmetical classics was a first step toward trigonometry, making it possible in effect to apply sine relations and a fair approximation of cosine relations (301; III. 39, with diagram). The great remaining lack, as in planetary theory, was a mass of fresh observations on which to base new parameters. That this weakness could threaten the continuance of the system became clear the year after it was adopted (1076), when the failure of a predicted lunar eclipse to occur left Shen and his associates open to attack. Shen parried with a successful request that astronomical students at the Han-lin Academy observatory be ordered to carry out his observational program "for three or five years" and to communicate the results to the original compilers. Whether this attempt to bypass the statement at the Astronomical Bureau's observatory was well-conceived remains unknown, for in the next year Shen's impeachment aborted it.

In sum, the immediate outcome of the Oblatory Epoch calendar reform was undistinguished, and within half a century the official documents embodying it had been lost. It is impossible to be sure, for instance, to what extent arc-sagitta relations had been incorporated after Shen invented them. But enough information survived in proposals, reports, Shen's writings, and compendiums of various sorts for his astronomical system to play a considerable part in the highest achievement of traditional Chinese mathematical astronomy, the Season-Granting (*Shou shih*[40]) system of Kuo Shouching[41] (1280). Kuo carried out a sustained program of observation using instruments that incorporated Shen's improvements. He took up Shen's arc-sagitta formula, greatly improving the cosine approximation, and applied it to the equatorecliptic transform. Aware of Shen's emphasis on the continuous variation of quantities in nature, and of his criticism of linear interpolation in clepsydra design, Kuo used higher-order interpolation to an unprecedented extent in his calendar reform.

Shen recorded another scheme for reform of the civil calendar that was most remarkable for his time and place. It almost certainly occurred to him in the last decade of his life. The traditional lunisolar calendar was a series of compromises in reconciling two incommensurable quantities. The modern value for the tropical year is 365.2422 days, and that for the synodic month 29.53059 days, so that there are roughly 12.37 lunar months per solar year. The practical problem was to design a civil calendar with an integral number of days each month, and an integral number of months each year, in such a way that the long-term averages approach the astronomical constants. Hardly two of the roughly one hundred computational systems recorded in early China solved this problem in exactly the same way, just as there was endless tactical variety in other traditional societies, but strategy was generally the same. Months of twenty-nine and thirty days alternated, with occasional pairs of long months to raise the average slightly. Intercalary thirteenth months were inserted roughly seven times every nineteen years, which comes to 0.37 additional months per year.

By a millennium before Shen's time the calendar was more than adequate in these respects for every civil need, although attempts to further refine the approximation led to endless retouching. The rhythms of administration, and to some extent of commerce, were of course paramount in the design of the lunisolar calendar, despite pieties about imperial concern for agriculture. It is most unlikely that Chinese peasants ever needed a printed almanac by which to regulate their activity; what they consulted, if anything, was its notations of lucky and unlucky days. Division of the year by lunar months is, in fact, useless for agriculture, since the seasons that pace the farmer's work vary with the sun alone. The Chinese calendar also incorporated twelve equal divisions of the tropical year (*ch'i*[30], like the Babylonian *tithis*), further subdivided into twenty-four periods with such names as Spring Begins, Grain Rains, and Insects Awaken. These provided a reliable notation for seasonal change in the part of northern China in which the series originated.

Shen's suggestion was a purely solar calendar, based on the twelve divisions of the tropical year (average 30,43697 days in his system) instead of on the lunation. The civil calendar would thus alternate months of thirty and thirty-one days, with paris of short months as necessary to approach the average. This would provide truly seasonal months and at the same time do away with "that goitrous excrescence" the intercalary month. "As for the waxing and waning of the moon, although some phenomena such as pregnancy and the tides are tied to them, they have nothing to do with seasons or changes of climate; let them simply be noted in the almanac" (545). Shen was aware that because the lunisolar calendar went back to hoary antiquity "it is by no means appropriate to criticize it." He predicted that his discussion "will call forth offense and derision, but in another time there will be those who use my arguments." This proposal was in fact considered by later scholars the greatest blemish on Shen's astronomical talent. His posterily appeared in the mid-nineteenth century, with the even more radical solar calendar enacted for a few years by the T'ai-p'ing rebels.[*] His work was

[*] Kuo T'ing-i,[42]*T'ai-p'ing t'ien kuo li-fa k'ao-ting*[43] ("Review of the Calendrical Methods of the T'ai-p'ing Heavenly kingdom," 1937; reprinted Taipei, 1963); Lo Erh-kang,[44]*T'ien li k'ao chi t'ien li yii yin yang li jih tui-chao-piao*[45] ("On the T'ai-p'ing Calendar, With a Concordance Table for the Lunar and Gregorian Calendars"; Peking, 1955).

cited to justify historically more respectable proposals between that time and the adoption of the Gregorian calendar in 1912.

Configuration and Change . Chinese natural philosophers, unlike the majority in the postclassical West, did not dismiss the possibility that terrestrial phenomena could conform to mathematical regularities. But given the strength of Chinese quantitative sciences in numerical rather than geometric approaches, the very late and partial development of mathematical generalization, and the complete absence of notions of rigor, it is only consistent that much of the effort to discover such regularities produced numerology. Thus the most obvious of Shen's contributions to understanding of the earth and its phenomena are qualitative.

Magnetism. For more than a millennium before Shen's time, south-pointing objects carved from magnetite had been used from time to item in ceremonial and magic, and in 1044 objects cut from sheet iron and magnetized by thermoremanence were recommended for pathfinding in a book on military arts. Shen took up the matter of needles rubbed against lodestone by contemporary magi, discussed floating and other mountings, recommended suspension, noted that some needles point north and some south, and asserted that "they are always displaced slightly east rather than pointing due south"—all in about a hundred characters (437; IV.1, 249–250). This recognition of magnetic declination depended not only on consideration of a suspended needle but also on the improved meridian determined by Shen's measurement of the distance between the polestar and true north; declination in his part of China at the time has been estimated as between five and ten degrees (Needham and Peter J. Smith, "Magnetic Declination in Mediaeval China," in *Nature* [17 June 1967], 1213–1214. See the historical table in *Science and Civilization in China*, IV.1, 310).

Shen may have been anticipated by geomancers, who practiced a sophisticated protoscience of land configuration and siting, but the dates of texts on which such claims have been based are questionable. The use of compass needles in navigation is recorded shortly after Shen's death, and later descriptions provide enough detail to show that the twenty-four-point rose that Shen substituted for the old eight compass points (perhaps also under the stimulus of the better meridian, if not of geomantic practice) had become widely used. He apparently was unaware of the polarity of magnetite itself, since in another article he explained the difference between north-pointing and south-pointing needles as "perhaps because the character of the stone also varies" (588; IV.1, 250).

Cartography. It has been conjectured that Shen was the first to use a compass in mapmaking, although traditional methods would have sufficed. Neither his early maps of Khitan territory nor the atlas of China completed in 1087 have survived to answer this question. But in an enclosure to the latter he did separately record bearings between points using his twenty-four-point compass rose, as well as rectilinear distances rather than, as customary, distances along established routes (he calls the use of distances "as the bird flies" ancient, but we have no earlier record). "Thus although in later generations the maps may be lost, given my book the territorial divisions may be laid out according to the twenty-four directions, and the maps speedily reconstructed without the least discrepancy" (575; III, 576). His great atlas included twenty-three maps drawn to a uniform scale of 1:900,000; the general map was ten by; twelve Chinese feet. There is no evidence that the handbook outlasted the maps.

Three-dimensional topographic maps go back at least to Hsieh Chuang[46] (421–466), who had a demountable wooden model carved, apparently on the basis of an ancient map. In 1075, while inspecting the Khitan border, Shen embodied information gathered from the commander and the results of his own travels in a series of relief maps modeled, for the sake of portability, in plastic media–wheat paste and sawdust until the weather turned freezing, then beeswax–on wooden bases. These were carried to the capital and duplicated in wood; similar models were thenceforth required from other frontier regions (472; III, 580).

Shen's regular use of both historical research and special on-the-ground surveys to solve such cartographic problems as tracing changes in water-courses also is noteworthy (431). Typical of his ingenious topographic survey methods were those used in 1072 to measure the slope of the Pien Canal near the capital. There he built a series of dikes in temporary, narrow parallel channels to measure incremental changes in water level (457; III, 577[*]).

Formation of the Earth. In 1704, in the T'ai-hang mountain range (Hopei), Shen noticed strata of "bivalve shells and ovoid rocks running horizontally through a cliff like a belt. This was once a seashore, although the sea is now hundreds of miles east. What we call our continent is an inundation of silt....This mud year by year flows eastward, forming continental land." A similar stratum had been observed long before by Yen Chench'ing[47] (708–784), who vaguely suggested its orgin in the sea; but Shen—whose duties had made him intimately familiar with the process of silting—opened a new line of investigation by proposing a mechanism (430; III, 604).

Probably on his southward drought survey earlier in the same year, Shen saw the Yen-tang range (Chekiang), a series of fantastic rock formations "invisible from beyond the ridgeline [opposite], but towering to the sky when seen from the valleys. If we trace the underlying pattern, it must be that great waters in the valleys have attacked and washed away all the sand and earth, leaving only the great rocks erect and looming up." His explanation proceeded to generalize the shaping role of erosion, and then to apply it to the hills that divide streams in the loess country of northwest China—"miniatures of the Yen-tang mountains, but in earth rather than stone" (433; III, 603–604).

Shen reported a variety of contemporary finds of petrified plants and animals (373–374; III, 614–618). He remarked particularly on a stony formation he identified as originally a grove of interconnected bamboo roots and shoots, found dozens of feet below ground level at Yenan (Shensi). He knew from his military service there that the climate was too dry to grow bamboo: "Can it be that in earliest times [literally, 'before antiquity'] the land was lower and the climate moister, suitable for bamboo?" (373). About a century later the great philosopher and polymath Chu Hsi[48] (1130–1200), who knew Shen's jottings well and often extended ideas from them in his teaching, suggested that the stone of certain mountains was itself petrified silt deposits. But Shen's notion of prehistoric climatic change, like that of the reshaping of land by erosion, was not pushed further soon after his lifetime.

Atmospheric Phenomena. Although Shen did not report important original discoveries of his own, he preserved a number of interesting observations not recorded elsewhere. Perhaps the most important is a vivid description of a tornado (385; translated in Holzman, “Shen Kua,” 286), the veracity of which was questioned by modern meteorologists until, in the first decade of the twentieth century, the Sikawei Observatory in Shantung reported phenomena of the same kind, previously though restricted to the western hemisphere. Shen was also responsible for transmitting an explanation of the rainbow by Sun Ssu-kung,[49] an elder contemporary in the court who was also considered one of the best mathematical astronomers of his era. “The rainbow is the image [literally, ‘shadow’] of the sun in rain, and occurs when the sun shines upon it. “This sentence does not, as often claimed, adduce refraction (pinhole or mirror images were regularly called “shadows”; see 44). Shen was prompted to determine by experiment that the rainbow is visible only opposite the sun (357). Later Chu Hsi, aware of Shen’s account, added that by the time the rainbow appears “the rain *ch’i*[30] has already thinned out: this in turn is because sunlight has shone on and attenuated the rain *ch’i*[30]*Ch’i* must mean vapor here; the notion of reflections off individual drops is, as in Sun’s explanation, implicit at best. Shen also recorded the fall of a fist-sized meteorite in more detail and with less mystification than previous reports. The particulars of its fall came from a careful account by another of Wang An-shih’s associates. The object was recovered and exhibited, but Shen did not claim that he himself had observed that it’s color is like that of iron, which it also resembles in weight” (340; III, 433–434).

Products of the Earth. Responsibilities with respect to fiscal policy gave shen a detailed knowledge of important commodities, their varieties, and the circumstances of their production, as may be seen from his descriptions of tea (208) and salt (221). Inflammable seepages from rock had been known a millennium before Shen’s time, and for centuries had been used locally as lamp fuel and lubricant. While civil and military commisisioner near Yen-chou, he noted the blackness of soot from petroleum and began an industry to manufacture the solid cakes of carbon ink used for writing and painting throughout China. Good ink was then made by burning pine resin, but Shen knew that North China was being rapidly deforested. He remarked that, in contrast with the growing scarcity of trees, “petroleum is produced in exhastibly within the earth,” The name Shen coined for petroleum[50a] is the one used today, and the source in Shensi province that he developed is still exploited. In the same article he quoted a poem of his that is among the earliest records of the economic importance of coal, then beginning to replace charcoal as a fuel (421; III 609, partial).

Optical Phenomena, shen’s interest in image formation was not directly connect with his worldly concerns. His motivation is more plausibly traced to the play of his curiosity over old artifacts than to the improvement of naked-eye astronomical instruments.

In the canons of the Mohist school (*ca*. 300 B.C.) is a set of propositions explaning the formation of shadows and of optical images (considered a kind of show) in plane, convex, and concave mirrors. One proposition is widely believed to concern pinhole images, although textual corruption and ambiguity make this uncertain. These propositions are in many respects correct, although very shematic, and rays of light are not presupoposed. Shen concerned himself with the single question of why a concave mirror forms an inverted image. He posited an “obstruction” (*ai*[50]), analogous to an oarlock, that constricts the :shadow” to a shape like that of a narrow-waisted drum—or, as we would put it, to form two cones apex to apex, the second constituting the inverted image. Like the Mohists, Shen clearly believed that inversion takes place before the image is reflected. he expressly likened the inverted image to that of a moving object formed on the wall of a room through a small opening in a paper window. Aware for the first time that there is a range of distances from a copncave mirror within which no image is formed (that is, between the center of curvature and the focal point), he explained that this blank region, corresponding to the pinhole, is the locus of “obstruction” (44; translated i A. C. Graham and N. Sivin, “A Systematic Approach to the Mohist Optics” in S. Nakayama and N. Sivin, eds., *Chinese Science; Explorations of an Ancient Tradition* [Cambridge, Mass., 1973], 145–147). His pinhole observation was adventitious, but his approach to the burning mirror was experimental in its details.

Two other observations of optical interest are found under the rubric “Artifacts and Implements,” The first, in the “Sequal to Brush Talks,” noted that when the ancients cast bronze mirrors, they made the faces just convex enough that, regardless of size, every mirror would reflect a whole face.By shen’s time this refinement had been abandoned and the reasoning behind the curvature forgotten, so that collectors were having the faces of old mirrors scraped flat (327; IV.I. 93).

The second jotting is the oldest record of a Far Eastern curiosity still being investigated: “magic mirrors,” or, as Shen called them, “transparent mirrors,” shen described a bronze mirror with a smooth face and an integrally cast inscription in relief on its back (both conventional features). When the mirror was used to reflect the sun onto a wall, the inscription was duplicated within the image. Shen cited with approval an anonymous explanation: “When the mirror is cast, the thinner parts cool first; the raised design on the back, being thicker, cools later and the shrinkage of the bronze is greater. Although the inscription is on the obverse, there are imperceptible traces of it on the face, so that, so that it becomes visible within the light.” He then qualified this explanation as incomplete, because he had tried mirrors in his own and other collections that were physically indistinguishable from the “transparent” ones and found that they did not cast images (330; IV.1, 94*). His doubt ws justified, although the approach taken by his informant was at least as good as those of some modern metallurgists. Although cooling rate plays no discernible part, the variation in thickness is indeed responsible for the image in this sort of mirror, the most common among several types extant. Filing considerable bronze off the face of the mirror after casting is the key. This releases tensions in the metal and gives rise to slight deformations that produce the image.

Productive Techniques and Materials . The technologies of Shen’s time were not cumulative and linked to science, but independent artisanal traditions transmitted from master to pupil. Shen left so many unique and informative accounts of ancient and contemporary processes among his jotting that “Brush Talks” has become a major source for early technology. Shen’s interests in contemporary techniques can in most cases be linked to broad concerns of his official career; but the exceptional richness of his official career; but the exceptional richness of his record bespeaks a rare curiosity, and the trenchancy of his descriptions a seriousness about mechanical detail unusual among scholar-officials. His notes on techniques lost by his time reflect the application of this technical curiosity and seriousness to archaeology, which was just becoming a distinct branch of investigation in the eleventh century.

Most of Shen's cultured contemporaries had a keen appreciation for good workmanship but considered the artisans responsible for it beneath notice except for occasional condescension. Shen wrote about resourceful craftsmen and ingenious laborers with much the same admiration he gave to judicious statesmen. He did not lose sight of the social distance between himself and members of the lower orders, but in his writing there is no snobbishness about the concert of hand, eye, and mind.

Contemporary Techniques. The most famous example is Shen's account of the invention of movable-type printing by the artisan Pi Sheng[51] (*fl*. 1041–1048). Shen described the carving and firikng of ceramic type and the method of imbedding and leveling them in a layer of resin, wax, and paper ash in an iron form, one form being set as a second is printed. As in xylography, water-base ink was used. Since the porous, thin paper took it up with little pressure, no press was needed. Shen also remarked, with his usual acumen, that the process could become faster than carving wood blocks only with very large editions[52] (the average then has been estimated at between fifty and a hundred copies). Unevenness of the surface and absorption of ink by the fired clay must have posed serious problems. Abandonment of the process after pidided was probably due to the lack of economic incentive that Shen noted. The long series of royally subsidized Korean experiments in the fifteenth century that perfected cast-metal typesetting still began with Pi Sheng's imbedding technique as described by Shen. Whether he knew Pi is unclear, but Shen's cousing preserved Pi's original font (307; translated in full, but not entirely accurately, in T. F. Carter. *The Invention of Printing in China and Its Spread Westward*, L.C. Goodrich, ed., 2nd ed. [New York, 1955], 212).

Shen left a number of descriptions of metallurgacal interest—for instnce, an account of the recovery of copper from a mineral creek by replacement of iron, a process then being carried out on an industrial scale to provide metal for currency (455; II, 267); observations of two of the three steelmaking processes used in early China (56; translated in Needham. *The Development of Iron and Steel Technology in China* [London, 1958], 33–34; the book was reprinted at Cambridge, England, in 1964); and remarks on a little-known cold-working method used by smiths of the Ch'iang[53] people of western China to make extremely tough steel armor (33). Water control techniques of which he records details include pound-locks with double slipwaus (213; IV.3, 351–352), and sectional gabions for closing gaps after embankment repairs (207; IV.3, 342–343).

Ancient Techniques. The concern for understanding ancient techniques began with the commentators on the Confucian and other classics more than a millennium earlier. Exegesis remained an important activity in China, and the productive methods of golden antiquity were investigated with the same assiduity as anything else mentioned in its literary ramains. For various reasons—among them the remains. For various reasons—among them the recovery of ancient artifacts in large numbers for the first time, the growth of collecting, and the elaboration of a conscious aesthetics—archaeology began to emerge from the footnotes less than a century before Shen's time, especially in monographs on ancient implements and ritual institutions. He was familiar with this literature and responded to it critically. Much of his writing in the "Artifacts and Implements" chapter falls squarely in this tradition, drawing on the testimony of both objects and books.

Shen's vision of the past as a repertory of lost processes introduced an influential new theme. A constant concern in his writing was not only that the workmanship of the past be esteemed for its excellence, but also that the present be enriched through understanding what the practical arts had been capable of. Although the belief was still current that the inventions that first made civilization possible were all due to semidivine monarchs of archaic times, in a letter Shen saw the technological past as successful for just the opposite reason; "How could all of this have come from the Sages? Every sort of workman and administrator, the people of the towns and those of the countryside—none failed to take part" (*Ch'ang-hsing chi* [1718 ed.], 19:53b).

Shen's remarks on magic mirrors are typical of his effort to understand lost processes. Another example is his reconstruction (and personal trial) of ancient crossbow marksmanship, interpreting a gnomic aiming formula in an ancient footnote with the aid of a graduated sight and trigger assembly that he examined after it was unearthed (331; III, 574–575*). The most famous instance of Shen's use of literary sources for the study of techniques has to do with the remarkable modular system of architecture used in public buildings. The set of standard proportions is well-known from an official compilation printed about a decade after Shen's death. Shen, by describing the proportion system of the Timberwork Canon (*Mu ching*[54]), attributed to a great builder of about 1999 and already falling out of use, demonstrates the antiquity of this art (299; IV.3, 82–83).

Medicine . By Shen's time medicine, which from the start drew heavily upon natural philosophy for its conceptual underpinnings, had accumulated a classical tradition. Not only was each new treatise conciously built upon its predecessors, but a major goal of new work was restoring an understanding that medical scholars believed was deepest in oldest writings. The revealed truth of the archaic canons was too concentrated for ordinary latter-day minds, who could hope to recapture it only as the culmination of a lifetime of study. Writers in the intervening centuries referred to the early classics as the ultimate source of significance even while aware that empirical and practical knowledge had considerably advanced since antiquity. The major contribution of the continuous tradition of medical writing was to fit new experiences into the old framework and, when necessary, to construct new framework in the feasible, standard editions of the chief classics were compiled and disseminated by government committees. This increased the respectability of the curing arts as a field of study. Large numbers of men from the scholar-official class began to take up medicine, not in but as a means of self-cultivation allied to cosmology and occasionally useful. The initial motivations commonly were personal ill health and the desire to serve one's sick parents.

Shen, as noted earlier, began the study of medicine early, for the former reason. One of his two therapeutic compilations survives in somewhat altered form. Its preface is a long disquisition on the difficult of adequate diagnosis and therapy, as well as on the proper selection, preparation, and administration of drugs. His criticism of contemporary trends toward simplification reminds us that the development of urban culture and education in Sung China had led to increased medical practice among ordinary people as well as study by the literati. As protoscientific medicine began to displace magico-ritual folk remedies (at least in the cities), there were more half-educated physicians to be criticized by learned amateurs such as Shen. Shen's most characteristic contribution was undoubtedly his emphasis on his own experience, unusual in a tradition whose literature in the Sung still tended to depend heavily on copying wholesale from earlier treatises. Shen not only omitted any prescription the efficacy of which he had not witnessed, but appended to most a description of the circumstances in which it had succeeded. He provided many precise descriptions of medicinal substances of animal, vegetable, and mineral origin. Although he had no more pharmacognostic scholars of his time, his concern for exact identification and for philological accuracy gave his critical remarks enduring value. Many were incorporated into later compilations on materia medica, and Shen's writing also served as a stimulus to the work a few decades later of the great pharmacognostic critic K'ou Tsung-shih[55] in his "Dilatations Upon the Pharmacopoeias" (*Pen-ts' ao yen i*,[56] 1116).

A recent discovery of considerable interest is that certain medical preparations from human urine collectively called "autumn mineral" (*ch'iu shih*[57]), which have a long history in China, contain high concentrations of steroid hormones and some protein hormones as well. In "Good Prescriptions" Shen gives one of the earliest accounts, in the form of detailed instructions for two such preparation that he performed in 1061 (other accounts by contemporaries are harder to date).[*]

Perhaps Shen's most famous writing on general medical matters is one in which he refutes the common belief that there are three passages in the throat — as shown, for instance, in the first book of drawings of the internal organs based directly on dissection (1045).[†] His supporting arguent is not from independent dissection but from sufficient reason "When liquid and solid are imbibed together, how can it be that in one's mouth they sort themselves into two throat channels?" He thus saw the larynx as the beginning of a network for distributing throughtout the body the vital energy carried in atmospheric air, and the esophagus as carrying nutriment directly to the stomach cavity, where its assimilation begins. This was a significant increase in clarity as well as accuracy (480).

A passage that has been praised for its simple but beautiful language takes issue with the ancient principle that medicinal plants should be gathered in the second and eighth lunar months (when they were thought easiest to identify). In a few hundred words it epitomizes the variation of ripening time with the therapy: the physiological effect needed for the application: altitude; climate; and for domesticated medicinal plants, variation with planting time, fertilization, and other details of horticulture. The sophistication of this passage reflects not only increasing domestication of drugs from every corner of China in to the expanding commercial network.

Conclusion . The expansiveness of Northern Sung society and its relative openness to talent, not to mention increasing government sponsorship of learning, made this an important period in the history of every branch of science and technology. Shen was not the first polumath it produced. There was also Yen Su[62] (*fl*, 1016). who designed an odometer and south-pointing chariot (in which a differential gear assembly kept figures pointing in a constant direction as the chariot turned), improved the design of the water clock and other astronomical instruments, adn wrote on mathematical harmonics and the tides. In Shen's lifetime there was Su Sung[63] (1020–1101), who was first privy councilor during the last part of the reaction against the New Policies (1092–1093). Through the 1060's he played as major part in a large imperially sponsored compliation of materia medica, and in the editing and printing of ancient medical classics. In 1088 a group that he headed completed a great water-driven astronomical clock incorporating an escapement device. Their detailed description of the mechanism included the oldest star map extant in printed form, based on a new stellar survey. (The book has been studied and translated in Wang Ling, Joseph Needham, Derek J. de Solla Price, et al., *Heavenly Clockwork* [Cambridge, England, 1960].) That Yen, Su, adn Shen were all in the central administration is not surprising. The projects on which they were trained and those in which they workeed out many of their ideas were of a scale that only the imperial treasury could (or at least would) support.

[*] See Lu Gwei-djen and Joseph Needham, "Medieval Preparations of Urinary Steroid Hormones." in *Medical History*, **8** (1964), 101–121; Miyashita Saburō[58], *Kanyaku shūseki no yakushigakuteki Kenkyu*[59] ("A Historical Pharmaceutical Study of the Chinese Drug 'Autumn Mineral' the *Ch'iu-shih*": Osaka. 1969). esp, 9–12.

[†] Persons untrained in medicine performed the dsicussion upon executed bandits in 1045 and recorded what was found under the direction of an enthusiastic amateur. Another episode of the same kind. Undertaken explicity to correct the earlier drawings, took place at the beginning of the twelfth centuary. There is no rteliable account of either in any European language, but see Watanabe Kōzō.[60] "Genson suru Chūgoku Kinsei made no gozō rokufu zu no gaisetsu"[61] ("A survey of Extant Chinese Anatomical Drawings Before Modern Times") in *Nihon ishigaku zasshi*, **7** (1956), 88.

Breadth of interest alone does not account for Shen's importance for the study of the Chinese scientific intellect. Another aspect is his profound technical curiosity. A number of the phenomena he recorded were mentioned by others; but even when other's descriptions happen to be fuller, they usually are of considerably less interest because their subject matter isd treated as a mere curiosity or as an occasion for anecdote rather than as a challenge to comprehension. Above all, one is aware in Shen, as in other great scientific figures of a special directness. A member of a society in which the weight of the past always lay heavily on work of the mind, he nevertheless often cut past deeply ingrained structures and assumptions. This was as true in his program of astronomical observations and his audacious solar calender as in his work as true in his work aware that man's world had greatly expanded since antiquity, adn questioning of precedent (in the name of a return to classical principles) was inherent in the New Policies. Shen's commitment to this political point of view can only have reinforced the sense of cumulative improvement of techniques and increasing accuracy over time that one finds in major Chinese astronomers. But given these predispositions and opportunities, shen remains in many senses an atypical figure, even in his time and among his associates.

There certainly is much that a modern scientist or engineer finds familiar, not only in the way Shen went about making sense of the physical world but also in the temper of his discourse, despite the profoundly antique nature of the concepts he used. One comes away from his writings confident that he would see much of modern science as a culmination (not the only possible culmination) of his own investigations—more confident than after reading Plato, Aristotle, or St. Thomas Aquinas. But does Shen's special configuration of abilities and motivations suggest that a genetic accident produced, out of time, a scientific rationalist-empiricist of essentially modern type? To answer this question it is necessary to look at Shen's larger conception of reality, of which his scientific notions compose only a part but from which they are inseparable.

The Relation of Scientific Thought to Reality, The sense of cumulative enterprise in mathematical astronomy did not imply the positivistic conviction that eventually the whole pattern could be mastered. Instead from the earliest discussions there was a prevalent attitude that scientific explanation–whether in terms of number or of abstract qualitative concepts, such as yin–yang–merely expressed, for human purposes, limited aspects of a pattern of constant relations too subtle to be understood directly. No one expressed this attitude more clearly than Shen. In instance after instance he emphasized the inability of secular knowledge to encompass phenomena: the reason for magnetic declination (437), why lightning striking a house can melt metal objects without burning the wooden structure (347), and so on.

Shen made this point most clearly in connection with astronomy. In one passage he discussed the fine variations that astronomers must, in the nature of their work, ignore. Every constant, every mean value obscures continuous variation of every parameters (123). In his official proposals on the artimaillary sphere, [64] he argued that measure is an artifact, that it allows particular phenomena to be "caught" (*po*[65]) in observational instruments. where they are no longer part of the continuum of nature. That Shen saw as the condition of their comprehensibility. This and similar evidence amount not merely to an appreciation of the role of abstraction in science, but also to the steady convi action that abstraction is a limited process incapable of producing universal and fundamental knowledge of the concrete phenomenal world. Nature is too rich, too multivariant, too subtle (*wei*[66]). This limitation did not detract from the interest or worth of theoretical inquiry, and did not lead intellectuals to question whether learning could contribute to the satisfaction of social needs; but the ambit of rationalism in traditional scientific thought was definitely circumscribed.

In this light Shen's explanatory metaphors become more comprehensible. In his remarkable suggestion that variations in planetary speed may be represented by a compounded figure, he chose to fasten to the periphery of his circle a willow leaf, whereas in Europe no figure but another circle was thinkable (148). When explaining optical image inversion in terms of converging and diverging rays, the images of the oarlock and wasted drum occurred to him (44). The variation in polarity of different magnetized needles was likened to the shedding of antlers by two species of deer in opposite seasons (588; IV.1, 250), and so on. Geometric figures, numbers, and quantities were useful for computation but had very limited value, not so great as cogent metaphors fro the world of experience, in understanding the pattern inherent in physical reality.

Many Chinese thinkers, even in the Sung, did believe in number as a key to the pattern of physical reality; but their search was concentrated in numerology (especially as founded on the "Great Commentary" to the *Book of Changes*) rather than in mathematics. This is not to imply that numerology was a distraction fro mathematics. The two were not considered alternate means to the same goal.

Other Kinds of Knowledge. Did Shen believe that other ways of knowing complemented and completed empirical and theoretical investigation? Aside fro mist scientific aspects, Shen's thought has been so little studied that only some tentative suggestions can be offered. Contemplation and disciplined self-examination were ancient themes in Confucianism, and by Shen's time illumination was widely considered among the learned as a source of knowledge complementary to that given by experience of the external world. The domestication and secularization of Buddhist and Taoist meditation were gradually leading to a more introspective and less ritualistic approach to self-realization. This tendency was later elaborated with great variety of emphasis and weight in the schools of neo-Confucianism.

To understand what part contemplation and meditation played in the thought of Shen Kua requires a clearer view than we now have of their currency and coloring in his time, of the considerable role of Wang An-shih's thought in his intellectual development, and of Shen's own attitudes as indirectly expressed in his literary remains. There is as yet no sound basis for evaluating his interest in Taoist arcana that seems to have peaked in his thirties, his public remarks that express sympathetic interest in illuminationist (Ch'an, Japanese "Zen") Buddhism, and his statement in an autobiographical fragment that Ch'an meditation was one of the things to which he turned his attention after retirement. In any case these involvements refract aspects of his epistemology that cannot be over looked without badly distorting our recognition of the whole.

Teraji Jun has recently demonstrated this point in examining how strong a factor in Shen's motivation and individuality was his belief in destiny and prognostication. There are crucial passages, especially in his commentary on Mencius, where Shen spoke of the necessity for choosing what is true and holding to it, and called the rule of the heart and mind by sensory experience "the way of the small man." The basis of moral chioice was ab autonomous inner authority defined in an original way but largely in Mencian terms, a centeredness "filling the space between sky and earth,: unquestionably linked with the self-reliance that marked his unhappy career.

It is not immediately obvious why someone who so valued individual responsibility should have been fascinated by fate and divination, which in fact are the themes of whole chapters of :Brush Talks." Shen does not seem to have viewed these enthusiasms as in conflict with his scientific knowledge. His delight in strange occurrences and his tendency to place matters of scientific interest under that rubric begin to make sense under the hypothesis that he accepted the odd, the exceptional, and the affront to common sense as a challenge for explanation at another time, or by someone else—without assuming that explanation was inevitable. In his hundreds of jottings on people, the person he chose to praise is most often the one who did not do the obvious thing, even when it seemed the sound thing to do.

At one point Shen provided a thoroughly rational explanation of the relations between fate and prognostication. The future can of course be fore known by certain people, he said, but it is a mistake to conclude that all matters are preordained. The vision of the future is always experienced in present time; the years in the interim also become simultaneous. One can do nothing to avoid an undesirable future so glimpsed. Authentic foreknowledge would have witnessed the evasive measures; a vision that failed to see them could not be authentic foreknowledge (350).

In addition to the visionary ability of certain minds, Shen pondered universally accessible methods of divination, which (he seems to have believed) do not describe the future or the spatially distant so much as provide counsel about them or aid thought about them. In one of his chapters, "Regularities Underlying the Phenomena," he explained why the same divinatory technique people, thus has no inherent verifiability. He quoted the "Great Commentary" to the *Book of Changes* to the effect that understanding is a matter of the clarity and divinity (in a very abstract sense) within one's mind. But because the mind is never without burdens, that hinder access to its divinity, Shen reasoned, one's communion with it may take place through a passive mediating object or procedure (144, 145). This divinity is, for Shen's sources, the moral center of the individual. Prognostication, however ritualized (as we would pit it), thus draws indirectly upon the power of self examination. Access to the future, whether by vision or by divination, is a perfectly natural phenomenon that is imperfectly distinct, on the one hand, from the moral faculties, the choices of which condition the future, and, on the other, from science, the rational comprehension of the natural order as reflected in all authentic experience.

Thus it appears that introspection supplemented by divinatory procedures was a legitimate means to knowledge in Shen Kua's eyes, just as painstaking observation and measurement of natural phenomena were another. He neither confused the two approaches nor attempted to draw a clear line between them. Nor was he inclined to assess the comparative importance of these ways of knowing.

The complementarity in Shen's attitudes toward knowledge is echoed by another in the external world of his work. Computational astronomy and divination of various kinds (including judicial astrology) were equally weighty functions carried out by the central government on the emperor's behalf, for both kinds of activity were established supports of his charisma. The need to combine science with ritual in this sphere is implied in an important memorial of Wang An-shih: because the monarch acts on behalf of the natural order, he can safeguard the empire and command the assent of the governed only through knowledge of nature. Ritually expressed awe of that order, without knowledge, is not enough (*Hsu tzu chih t'ung chien ch'ang pien*[67] ["Materials for the Sequel to the Comprehensive Mirror for Aid in Government"], presented to the throne 1168 [1881 ed.,], 236:16b). Teraji has acutely pointed out that this is precisely the political justification for Shen's research, and the reason that traditional bureaucrat-scientists who were concerned mainly with maintaining ancient practices were not what Wang wanted.

Confucianism and Science. Recent attempts in both East and West to construct a historical sociology of Chinese science have in large part been built around a contrast between Confucianist and Taoist ideology. The values of the Confucian elite are often described as oriented toward stasis hierarchy, bureaucracy, and bookishness. These characteristics are seen as perennially in tension with the appetite of socially marginal Taoists for novelty and change, their tendency to contemplate nature and the individual in it as a system, and their fascination with techniques, which kept them in touch with craftsmen and made them willing to engage in manual work themselves. It will no doubt be possible eventually to excavate a falsifiable, and thus historically testable, hypothesis from the mound of observations and speculations in this vein that have accumulated over the last half-century. For the moment, all one can do is point out how relentlessly unsociological this discussion has been.

Sociology is about groups of people. Doctrines are germane to sociology to the extent that their effect on what groups of people do, or on how they form, can be demonstrated. Generalizations about people who accept a certain doctrine have no sociological significance unless such people can be shown to act as a group, or at least to identify themselves as a group. The term "Confucian" is commonly used indifferently even by specialists to refer to a master of ceremonial, a professional teacher of Confucian doctrines, a philosopher who contributes to their elaboration, someone who attempts to live by Confucius' teachings, any member of the civil service, any member of the gentry regardless of ambition toward officialdom, or any conventional person (since it was conventional to quote Confucian doctrines in support of conventional behavior). A "Taoist" can be anyone from a hereditary priest ordained by the Heavenly Master to a retired bureaucrat of mildly unconventional to a retired bureaucrat of mildly unconventional tastes living on a city estate. Either group, by criteria in common use, includes people who would make opposite choices on practically any issue. This being so, the proposition "Taoists were more friendly toward science and technology than Confucians" reduces to "Educated individuals who hold unconventional sentiments are more inclined to value activities unconventional for the educated than are educated people who hold conventional sentiments." That is probably not quite a tautologous statement, but it is sociologically vacuous and historically uninteresting.

Unease of this sort is probably the most obvious outcome of reflection on Shen Kua's career. By sentimental criteria he can be assigned to Confucianism, Taoism, or Buddhism, to suit the historian's proclivities.[*] He was a member of the elite a responsible official, a writer of commentaries on several of the Confucian classics, and a user of the concepts of Confucius' successor Mencius to explore the depths of his own identity. He spoke well and knowledgeably of Buddhism. He practiced arcane disciplines, such as breath control, that he called Taoist.

As for his allegiances, Shen was prominently associated with a powerful but shifting group of background very generally similar to his own. Social stasis and institutional fixity were impediments to their aims in reshaping government. At the same time, the new balance of power toward which they strove was more authoritarian than the old. Underlying their common effort was an enormous disparity of motivation, from the well-intentioned (Shen) to the simultaneously manipulative and corrupt (Ts'ai Ch'ueh).

Were these Confucians more or less Confucian than their Confucian opponents? Wang An-shih earned enduring stature for his commentaries on the classics and his though on canonic themes. His followers seem to have found inpiration in the

[*] A new element was introduced in 1974 in a book issued as part of the "anti-Confucius anti-Lin Piao" campaign against current ideological trends. Two of its essays (pp, 118–140) portray Shen as a legalist and a relentless opponent of Confucianism, "Legalist" is a tem applied to writers on government and administration concentrated in the last centuries before the Christian era. especially those who argued that polity must be built on law and regulation, in contrast with the traditionalist faith of Confucius in rites and moral example. Although the arguments in this book are too distorted and too selective in their use of sources to be of interest as history, they become intelligible when "legalism" and "Confucianism" are understood as code words for the political convictions of two contending power groups in China today, as portrayed by spokesmen for one of the two. The book is *Ju-Fa tou-cheng yü wo kuo ku-tai Ko-hsueh chi-shu ti fa-chan*[68] ("The Struggle Between Confucianism and Legalism and the Development of Science and Technology in Our Country in Ancient Times"; Peking, 1974). The first printing was 31,000 copies.

classics as often as their enemies and as those who avoided taking a political position. This is not to say that everyone understood the Confucian teachings in the same way. The latter were not, from the viewpoint of intellectual history, a set of tightly linked ideas that set fixed limits on change; rather, they were a diverse and fragmentary collection of texts reinterpreted in every individual and group who looked to them for guidance when coping with problems of the moment.

The major commentaries, which attempted to define the meanings of Confucian teachings philologically, carried enormous authority; and governments (that of Wang An-shih, for instance) repeatedly attempted to make on interpretation orthodox. But the urge to pin down meanings was always in conflict with precisely what made these books classic. Their unlimited depth of significance depended more on what could be read into them than on precisely what their authors had meant them to say. That depth made them applicable to an infinity of human predicaments and social issues, unprecedented as well as perennial. Late neo-Confucian philosophers striking out in new directions demonstrated again and again how little the bounded intellectual horizons and social prejudices of the classics' authors objectively limited what may be drawn from them.

In other words, the Confucian canon had the influence it did because it provided a conceptual language that over the centuries educated people used and redefined in thinking out decisions and justifying action and inaction. The classics were often cited as a pattern for static social harmony and willing subordination in arguments against the New Policies. Shen, on the other hand, used them to argue for flexibility in social relations and for greater receptivity toward new possibilities than was usual in his time, Either as a social institution or as ideology, Confucianism is too protean and thus too elusive a base generalizations about the social foundations of science and techniques in China.

Institutions also changed constantly, but at least they were tangible entities. It is essential to consider them when tracing the social connections of science. Very little is know about how scientists were educated in the Northern Sung period; the obvious next step is a collective study of a great many biographies. In She's case we can see a pattern that certainly was not unique. He was, so far as we know, self-educated in astronomy, but with many learned associates to draw upon. In medicine and breath control he probably received teaching in the traditional master-disciple relationship, Defined in the ages before printing made possible access to large collections of books, this relationship involved the student's memorizing the classics (more often one than several) that the teacher had mastered. This verbatim transmission of a text was supplemented by the teacher's oral explanations, The relation was deepened by ceremonial formality; the master took on the obligation to monitor the disciple's moral as well as intellectual growth, and the disciple accepted the responsibility of becoming a link in an endless chain of transmission. Schools were largely communities of masters and disciples. The scale of government-sponsored elementary schools in the provinces was small in Shen's youth, and began to compete with private academies only in the New Policies period. The two sorts together did not server more than a small minority of youth.

By the eighth century there were small schools in the central government to train technical specialist. The masters, usually several in number, were functionaries, representing the departments of the bureau that the disciples were being trained to staff. The schools for medicine and astronomy could not lead to the top of government, but guaranteed steady advancement between minor sinecures. Very few of the great physicians or astronomers of traditional China began in these schools.

In the absence of evidence to the contrary, there is no reason to believe that Shen Kua ever attended a school of any sort, nor does that make him untypical. His early education by his mother, his training in medicine by an obscure physician and others who remain unknown, and his catch-as-catch-can studies of most other matters do not set him apart from his contemporaries. With no knowledge of particulars one cannot even guess how his personal style in technical work was formed. But to say that we are ignorant is not to say everything. the intimate relations of master and teacher and the isolation of the autodidact were themselves important institutions in the Northern Sung, institutions of a sort that did not discourage the emergence of unforeseen abilities in the small number of people who had the opportunity to be educated. Shen did not have to cope with a standard curriculum, for better or worse. If we are searching for the decisive curriculum of science and technology, it is necessary to look outside the realm of education.

The Civil Service and Science One institution above all others influenced the mature ideas and attitudes of the ruling stratum: the bureaucracy. what can be said about its influence of science and technology in the life of Shen Kua? First, like very bureaucracy, it depended upon science and technology. It supported both sorts of activity on a scale otherwise unattainable, and unheard of in Europe at the time. Shen's curiosity, experience, and skills were so largely shaped by the civil service that it is absurd to ask what he would have become had he lived as a country gentleman or a aoist priest. On the other hand, as elsewhere, technicians were certainly less important to the priorities of the state than administrators. The responsibility of the former was to provide the emperor and his administrators with wealth and other tools for the realization of policy. Specialist positions in science and engineering did not often serve the beginnings of great careers.

By the New Policies period a career stream for economic experts had been established. It could assimilate people who combined technological cumen with fiscal skills, and carry them to the central councils of the empire. Shen's early technical feats were performed in general administrative boosts, but his talents came to be valued and he ose quickly through formal and informal structures. It is not irrelevant that his directorship of the Astronomical Bureau was never more than a concurrent position. His attempt to combine an effective voice in the shaping of change with scientific contributions ended in personal disaster. He was ruined by men of his own faction, apparently or his political seriousness and naïveté. His astronomical work was rendered futile by subordinates because of his professional demands upon them. The bureaucracy was not neutral; it was two-edged sword.

The civil service provided a form for great protects in science and technology, and practically monopolized certain disciplines, such as mathematical astronomy and observational astrology. Printing gave it the wherewithal to determine much of the content of elementary technical education (as in medicine and mathematics). A man of Wei u's genius. who had not had the opportunity to enter the bureaucracy by a regular route, was then himself chosen to be a mere technician, his standing in the civil service would have been sufficient to protect him from personal attack. He would have had more time but less power. He would have had more time but less power. It would be rash indeed to speculate that his calendar reform would not have failed. But there is a larger issue.

Shen's mind was shaped for the civil service, as were those of his ancestors and peers, by an early education centered in moral philosophy and letters. He was a generalist. The development of depth in thought and work was left to his own proclivities. Only a superficial knowledge of technical matters was expected of him as a youth—a situation not very different from that of the British civil service generalist of some decades ago. Shen's growing responsibilities in fiscal affairs were the one aspect of his career that we can be sure encouraged him to draw coherence out of his varied experiences and studies. For this reason and others of which we are still ignorant, the great breadth of his knowledge was accompanied by enough depth to let him write monographs of some importance and, even through his brief jottings, to reshape Chinese knowledge of certain phenomena. But distraction is a theme that runs through his writings: promising studies laid aside; endless skirmishes to defend administratively measures that spoke for themselves technically and strategically; proposals negated by political setbacks. Regardless of his capacity for scientific depth and his willingness to find his way to it, the sheet busyness of his career drastically limited him. The works of his final leisure, however valuable, were all superficial inform. Was this the result of habit, of distance necessitated by disillusion, or of an aesthetic choice of the style appropriate for conversing with one's of the style appropriate for conversing with one's brush and ink slab in a silent garden? That remains for deeper study to decide.

What, then, was responsible for Shen Kua's scientific personality? We do not know the answers to all sorts of prior questions. The greatest difficulty comes in learning what these questions should be—in isolating the important issues, in coming to terms with the paucity and partiality of the sources, and in doing justice to a rich mind that, despite its absorption in a quest that transcends people and eras, partook fully of its time and place. It is not a matter of mechanically juxtaposing the usual factors: intelligence, subjectivity, philosophical convictions, social background, career, and other experiences. We have already seen how problematic the last three are. The most conspicuous traits of Shen's consciousness were open curiosity, mental independence (without the intolerance for intellectual disagreement that was a major limitation of Wang An-shih), sympathy for the unconventional, ambition, loyalty, and lack of snobbishness. The first four are considered marks of promise among technical people today, although one often meets great scientists who lack one or more of them. Were these characteristics in Shen due to heredity, to early experiences and education, or to influences encountered in adult life? This is an example of the sort of question that bars understanding; surely Shen was the sum of all three. The secret of his uniqueness will not yield itself to historical method, however powerful, unless it is applied with imagination, artifice, and awareness of the springs of human complexity

Attitudes Toward Nature. When examined closely, attitudes toward nature in the late eleventh century become as elusive as attitudes toward Confucian humanism. The richly articulated philosophic vision of man in harmony with his physical surroundings was proving quite incapable of preventing the deforestation of northern China, which was virtually complete a generation after Shen's death. One cannot even speak of the defeat of that vision in an encounter of ideas, for no intellectual confrontation is recorded. What happened? The most obvious part of the answer is that the people who were chopping down the trees for charcoal were not the people who were seeking union with the ineffable cosmic Tao. Since that social difference was of very long standing, however, it does not explain the crescendo of exploitation in the Northern Sung. The coincidence of that fateful shift with the rise of large-scale industry and market networks is again obvious enough. [*] What needs to be explained, in fact, is the survival of the naturalist ideal until modern times.

The dilemma emerges clearly in the attitudes of Shen Kua and Wang An-shih toward nature. The orientations that pervade "Brush Talks" are in most respects the same as those of literati thinking about nature a millennium earlier. Philosophical pigeonholes are largely beside the point. Some "Confucians" though about nature a great deal, and some, convinced that human society is the sole proper object of reflection and action, as little as possible: but their perspectives were, on the whole, the ones common to all Chinese who could read and write. Nature was an organismic system. its rhythms cyclic and governed by the inherent and concordant pattern uniting all phenomena.

[*] It was made obvious in a brilliant series of papers by Robert M. Hartwell: "A Revolution in the Chinese Iron and Coal Industries During the Northern Sung, 960–1126 A. D.," in *Journal of Asian Studies*, **21** (1962). 153–162: "Markets. Technology, and the Structure of Enterprise in the Development of the Eleventh-Century Chinese Iron and Steel Industry," in *Journal of Economic History*, **26** (1966), 29–58:" A Cycle," in Economic Change in Imperial China: Coal and Iron in Northeast China, 750–1350," in *Journal of the Economic and Social History of the Orient*, **10** (1967), 102–159.

It comes as a shock to see Shen's definition of salt in a memorial: "Salt is a means to wealth, profit without end emerging from the sea" (*Hsu tzu chih t'ung chien ch'ang pien*, 280:17b–21b). This was not a slip, nor is it difficult to find philosophical precedents. Shen saw the fiscal function of the state (for which he briefly had supreme responsibility) as the provision of wealth from nature. His recommendations encouraged extractive industries and manufactures, and mobilization of the popular strength for land reclamation, in order to increase national wealth. In that respect he was faithful to the priorities of Wang An-shih. This is a far cry from the senior civil servant in China in the 1960's designing a campaign to convince farmers that nature is an enemy to be conquered, tamed, and remolded to social ends. But neither is it the pastoral ideal.

Why this discrepancy between nature as the ideal pattern to which man adjusts and nature as a (still beneficent) means of enrichment? Why does Shen seem not to be conscious of it as contradictory? These are questions on which the research has yet to be done. But Shen Kua's career, considered in the round, suggests a working hypothesis. Such notions as yin-yang, the Five Phases, and certain related ideas associated with the *Book of Changes* are often considered to have been hindrances to an autochthonous scientific revolution in traditional China. This is, of course, an elementary fallacy, comparable to considering the rail-road, because it filled a need satisfactorily for so long, an impediment to the invention of the airplane. The old Chinese world view had much in common with cosmological ideas practically universal in Europe until the consummation of the Scientific Revolution—the four elements and so on—but that gave way soon enough. Historically speaking, Chinese organismic naturalism was not a rigid framework of ideas that barred change; rather, it was the only conceptual language available for thinking about nature and communicating one's thoughts, new or old, to others. Like any language, it imposed form and was itself malleable. Its historical possibilities were less a matter of original etymology or definition than of the ambiguity and extensibility that let people in later ages read new and often drastically changed import into old words. There is no true paradox in appeals to the harmony of man and nature by Shen and others before and after him who favored the exploitation of nature in the interests of the state. Although such activist thinkers stretched the old pattern of understanding, its fabric remained seamless. Their definition of what they wanted could not transcend it. Only the more desperate urgencies of another time could finally stretch it until it tore.

BIBLIOGRAPHY

I. Original Works. The best attempt at a complete list of Shen's writings is in an appendix to Hu Taoching's standard ed. of "Brush Talks,' *Meng ch'i pi t'an chiao cheng*[69] ("Brush Talks From Dream Brook, a Variorum Edition"), rev. ed., 2 vols.(Peking, 1960 [1st ed., Shangai]), 1151–1156. There are forty titles, including some only mentioned in early writings about Shen. A portion of the list belongs to parts or earlier versions of larger writings. It has been suggested that the high rate of attrition was due to the campaign of Ts'ai Ching[70] (1046–1126), virtual dictator during the revival of the New Policies in the first quarter of the twelfth century, to obliterate the literary remains of his predecessors as well as their enemies. (See Ch'en Tengyuan,[71]*Ku-chin tien-chi chü-san k'ao*[72] ["A Study of the Collection and Dispersion of Classical Writings in Ancient and Modern Times"; Shanghai, 1936], 54.) Six works are extant, although only two appear to be substantially unaltered, and considerable fragments of four others exist. Those of scientific interest are described below:

1. *Meng ch'i pi t'an*[21] ("Brush Talks From Dream Brook"), written over the greater part of Shen's retirement and possibly printed during his lifetime. It was first quoted in a book dated 1095. Originally it consisted of thirty *chüan* (a chapterlike

division); but all extant versions, descended from a xylograph of 1166, follow an unknown prior editor's rearrangement into twenty-six *chüan*. The editor of the 1166 reprint noted a number of errors already in the text that he could not correct for want of variants. There are 587 jottings.

The practically definitive ed. of this book and its sequels (items 2 and 3 below), and in many other respects the foundation of future studies, is the Hu Tao-ching recension mentioned two paragraphs above. It includes a carefully collated and corrected text with variorum notes and modern (but occasionally faulty) punctuation, based on all important printed versions and on five previous sets of notes on variants. It also provides exegetic and explanatory notes and generous quotations from documents concerning Shen, from his other books, from the reflections of other early writers on his subject matter, and from modern Chinese (and to some extent Japanese and Western) scholarship. Appendixes include thirty-six additional jottings or fragments that have survived only in the writings or compilations of others; all known prefaces and colophons: notes on eds. by early bibliographers and collators; a chronological biography: a list of Shen's writings; and an index to names and variant names of all persons mentioned in "Brush Talks" (a tool still very rare in Chinese publications). A l-vol. version of the text with minimal apparatus was published by Hu as *Hsin chiao cheng Meng ch'i pi t'an*[73] ("Brush Talks From Dream Brook, Newly Edited"; Peking, 1957).

2. *Pu pi t'an*[74] ("Supplement to Brush Talks"), listed in most early bibliographies are two *chüan* but rearranged into three *chüan* with some alteration of order in the 1631 ed. Ninety-one jottings. Hu suggests that this and the next item were edited posthumously from Shen's notes. There is even stronger evidence for this hypothesis than he adduces, for some articles appear to be rejected drafts of jottings in "Brush Talks" (compare 588 with 437, 601 with 274).

3. *Hsu pi t'an*[75] ("Sequel to Brush Talks"), eleven jottings in one *chüan*, mostly on literature.

4. *Hsi-ning Feng-yuan li*[76] ("The Oblatory Epoch Astronomical System of the splendid Peace Reign Period," 1075), lost, but listed in a Sung bibliography as seven *chüan*. This was the official report embodying Shen's calendar reform. It would have followed the usual arrangement, providing lists of constants and step-by-step instructions for computation, with tables as needed, so that the complete ephemerides could be calculated by someone with no knowledge of astronomy. Since a *Hsi-ning F eng-yuan li ching*[77] ("Canon of the Oblatory Epoch Astronomical System...") in three *chüan* is separately recorded, the remaining four *chüan* may have been, as in other instances, an official critique (*li i*[78]) outlining the observational basis of the system and reporting on tests of its accuracy. The Sung standard history also records a ready reckoner (*li ch'eng*[79]) in fourteen *chüan*, used to simplify calculations, and a detailed explanation of the mathematics with worked-out examples (*pei ts'ao*[80]) in six *chüan*. Surviving fragments of the basic document have been gathered by the great student of ancient astronomy Li Jui[81] (1765–1814) under the title *Pu hsiu Sung Feng-yuan shu*[82] ("Posthumous works of Mr. Li," 1823).

5. *Liang fang*[19] ("Good Prescriptions"), a work of ten or fifteen *chüan* compiled during Shen's retirement. In the Sung it was combined with a smaller medical miscellany by the greatest literary figure of Shen's time, Su Shih[84] (1036–1101), a moderate but influential opponent of the New Policies. The conflation is called *Su Shen nei-han liang fang*[85] ("Good Prescriptions by the Hanlin Academicians Su and Shen"),often referred to as *Su shen liang fang*. The most broadly based text is that in *Chih pu-tsu chai ts'ung-shu*[86] collection and modern reprints descended from it. One copy of an illustrated Ming ed. still exists. Shen's original compilation was lost sometime after 1500. There is some overlap between *chiian* 1 of *Su Shen liang fang* and jottings in *chiian* 26 of Meng ch'i pi t'an; see the comparison in Hu's *Chiao cheng*, pp. 880–882. A lost collection of prescriptions in twenty *chüan, Ling yuan fang*[87] ("Prescriptions From the Holy Garden"), is quoted in Sung treatises on materia medica. Hu has shown that it was written before *Liang fang (Meng ch'i pi t'an chiao cheng*, pp. 830–831).

6. *Wang huai lu*[20] ("Record of Longings Forgotten"). three *chüan*, complied during Shen's retirement. It incorporates a lost book of observations on mountain living written(or at least begun) in Shen's youth and entitled *Huai shan lu*[88] ("Record of Longings for the Mountains"). His retirement to Dream Brook satisfied his early longings. hence the title of the later collection. It was lost soon after his death. The ionly well-known excerpts, in the *Shuo fu*[89] collection, ar on implements useful to the well-born mountain dweller, but Hu TAo-ching in a recent study has sho\wn that the book was correctly classified by early bibliographers as agricultural. see. "Shen Kua ti nung-hseuch chu-tso *Meng ch'i Wang huai lu*"[90] ("Shen Kua's Agricultural work... "), in *W en Shih*,[91]**3** (1963), 221–225. Hu's collection of all known fragments has not yet appeared.

7. *Ch'ang-hsing chi*[92] ("Collected Literary Works of [the Vsicount of] Ch'ang-hsing"), originally forty-one *Chüan*, almost certainly a posthumous compilation. Includes prose, poetry, and administrative documents prized for their language. By the time this work was reprinted in the Ming (*ca*, fifteenth century), only nineteen *chüan* of the Sung version remained. An additional three *chüan* were collected from other works and printed at the head of the recession in *Shen shih san hsien-sheng wen chi*[93] (1718). This is now the best ed. available. The collection includes important astronomical documents and a great deal of information on Shen's intellectual formation, in particular his commentary on Mencius (*Meng-fzu-chieh*[92]) in *chüan***23**

The only book in any Western language that translates more than a few examples of Shen's writings is Joseph Needham *et al., Science and Civilisation in China*, 7 vols. projected (Cambridge, 1954), particularly from vol. III on. The translations always occur in context, usually with fuller historical background than given in Chinese publications. Occasionally the English version is extremely free "Dream Pool," Translations into modern Chinese are sprinkled through Chang Chia-chü, [93]*Shen Kua* (Shanghai, 1962), A complete Japanese trans, of "Brush Talks" and its sequesl is an ongoing project of the History of Science Seminar, Research Institute for Humanistic Studies (Jimbun Kagaku Kenkyūsho[96]), Kyoto University. A representative selection of English translations will be included in a sourcebook of Chinese science being compiled by N. Sivin.

II. Secondary Literature. There is no bibliography devoted to studies of Shen's life or work, but most primary and secondary sources in Chinese have been cited in Hu's ed. or in the footnotes to the biography of Shen by Chang Chia-chü (see above). The latter is the fullest and most accurate account of Shen's life, and pays attention to the whole range of his work. It is generally critical in method, but sometimes careless. Like other recent Chinese accounts, it is extremely positivistic, patronizing toward "feudal" aspects of Shen's mentality, and inclined to exaggerate his sympathies toward the common people. A concise survey of Shen's life and positive contributions by a great historian of mathematics is Ch'ien Pao-tsung,[97] "Shen Kua," in seminar in the History of the Natural Sciences, ed., *Chung-kuo ku-tai k'o-hsueh-chia*[98] ("Ancient chinese scientists": Peking , 1959), 111–121. Another work of interest by Hu Tao-ching, overlapping to some extent the preface to his ed. of "Brush Talks," is "Shen Kua ti cheng-chih ch'ing-hsiang ho t'a tsai k'o-huseh ch'eng-chiu-shang ti li-shih t'iao-chien"[99] ("Shen Kua's Political Tendencies and the Historical Conditions Bearing on His Scientific Acoomplishments"), in Li Kuang-pi and Ch'ien Chün-yeh,[100] eds., *Chung-kuo li-shih jen-wu lun-chi*[101] ("Essays on Chinese Historical Figures": Peking, 1957), 330–347. Its summary of scientific and technical accomplishments in the Northern sung period from 960 to *ca*. 1100 is especially useful.

In addition to discursive biographical studies Shen's life has been the subject of four chronologies (*nien-p'u*[102]) an old form in which individual events are simply listed year by year along with related data. The fullest in print (although obsolete in a number of respects) is Chang Yin-lin, [103] "Shen Kua pien nien shih chi" [104] ("A Chronicle of Shen Kua") in *Ch'ing-hua hsueh-pao*[105]**11** (1936), 323–358. That appended to the 2-vol. Hu Tao-ching ed. of "Brush Talks," 1141–1156, is especially handy because of its references to jottings and to sources cited in the book's notes. The most up-to-date and accurate chronology is the one at the end of Chang Chia-chü, *Shen Kua*, 235–259. Hu Tao-ching, in his colophon to the 1960 ed. of "Brush Talks," remarked that his own book-length chronology was in the press, but it has not yet appeared.

Yabuuchi Kiyoshi,[106] Japan's leading historian of science, has provided a characteristically reflective discussion of the historic circumstances of Shen's career in "Shin Katsu to sono gyõseki,"[107] ("Shen Kua and His Achievements"), in *Kagakushi kenkyū*, [108]**48** (1958), 1–6. The most stimulating contribution to the study of Shen i nthe past decade is Teraji Jun, [109] "Shin Katsu no shizen kenkyū to sono haikei"[110] ("The Natural Investigations of Shen Kua and Their Background"), in *Hiroshima daigaku bungakubu kiyõ*, [111]**27** no. 1 (1967), 99–121. Rejecting the prevalent tendency to prove Shen's greatness by citing anticipations of European science and technology, the author has made a fruitful and original effort to grasp the inner coherence of his thought and work. This article provided a point of departure for the first two sections of the "Conclusion" of the present article.

The first, and so far the only, European introduction to Shen's life is Donald Holzman, "Shen Kua and his *Meng-ch'i pi-t'an*," in *T' oung Pao* (Leiden), **46** (1958), 260–292, occasioned by the first publication of Hu's ed. of "Brush Talks". In addition to providing a critical and Well-proportioned biographical sketch, Holzman had aid more attention to Shen's humanistic scholarship than has any other author discussed in this section. He also considers some of the evidence for Shen's position in the history of science, but reaches no conclusion. He tends to ask whether Shen's ideas are correct from today's point of view rather than what they contributed to better understanding of nature in the Sung. The most reliable and compendious introduction to the New Policies is James T. C. Liu, *Reform in Sung China, Wang Anhih (1021–1086) and His New Policies* (Cambridge, Mass., 1959). A full-length intellectual biography of Shen is under way by N. Sivin.

The first modern study of any aspect of Shen's interests, largely responsible for the attention paid him by Chinese educated in modern science, is Chu K'o chen,[112] "Pei Sung Shen Kua tui-yü ti-hseh chih kungasien yü chi-shu" [113] ("Contributions to and Records Concerning the Earth Sciences by Shen Kua of the Northern Sung Period"), in *K'o-hseuh*,[114]**11** (1926), 792–807. Chu's erudite and broadly conceived article had influenced much of the later writing on the subject. A great number of observations on Shen's scientific and mechanical ideas are distributed through Needham *et, al*., *Science and Civilization in China*, as well as through the topical studies by leading Japanese specialists in Yabuchi Kiyoshi, ed., *Sõ Gen jidai no kagaku gijutsu shi*[115] "History of Science and Technology in the Sung and Yuan Periods"; Kyoto, 1967).

There is no recent investigation in depth of Shen's astronomical activities, but a good technical description of what were traditionally considered his most important contributions is found in Juan Yuan,[116]*Ch'ou jen chun*[117] ("Biographies of Mathematical Astronomers" [1799]; Shanghai, 1935), 20:238–243. Shen's most noteworthy mathematical problems have been studied in the various articles in Ch'ien Pao-tsung, ed., *Sung Yuan shu-hsueh-shih lun-wen-chi*[118] ("Essays in the History of Mathematics in the Sung and yuan Periods"; Peking, 1966). The considerable portion of "Brush Talks" devoted to music is evaluated and used in Rulan C. Pian, *Sonq* [*sic*] *Dynasty Musical Sources and Their Interpretation* (Cambridge, Mass., 1967) esp. 30–32 Shen's ideas concerning economic theory, the circulation of money, and similar topics have been related to traditions of thought on these subjects in an unpublished study by Robert M. Hartwell, A number of interesting ideas are found in Sakade Yoshinobu's[119] positivistic discussion of Shen's use of theory, "Shin Katsu no shizenkan ni tsuite"[120] ("On Shen Kua's Conception of Nature"), in Tõhõgaku,[121]**39** (1970), 74–87. Shen's remarks on ancient techniques are elucidated in hsia Nai,[122] "Shen Kua ho *K'ao-ku,*[124] no. 5 (1974), 277–289, also in *K'ao-ku hsuh-pao,*[125] no. 2(1974), 1–14, with English summary, 15–17

N. Sivin